PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicants:	DOUCET et al.	Examiner:	GOLUB, Marcia A.
Serial No.:	10/665,138	Group Art Unit:	2828
Filed:	September 18, 2003	Docket No.:	U014823-0
Customer No.	00140	Confirmation No.	5809
Title:	MULTI-WAVELENGTH LASER SOURCE		

DECLARATION OF DR. PETER KRUG

I, Dr. Peter Krug, residing at 23 Dalecroft Crescent, Ottawa, in the Province of Ontario, Canada declare as follows:

1. I am a Senior Scientist in the Advanced Photonic Components Group at the Department of Electronics of Carleton University in Ottawa, Ontario, Canada.

2. I have been involved in research, development and testing of photonic components, including gratings, used in lasers and other optical devices for over 20 years. Before joining Carleton University's Department of Electronics, I worked at or as a consultant for several companies, including Dipix Technologies, Spartan Bioscience, OneChip Photonics, Numetrica, EcoVu, Metconnex, Optenia, and Zenastra Photonics (where I managed grating research), as well as at research centers, including the Centre for Ultrahigh Bandwidth Devices and the Optical Fibre Technology Centre of the University of Sydney in Australia. In addition, I was the Fiber Optics Topical Editor for *Applied Optics* from 1995 to 1997, and I have been a member and subcommittee chairman of the Technical Program Committee of the Optical Fiber Communication (OFC) Conference. I have also published and presented numerous papers on gratings and I am a named inventor on two U.S. patents pertaining to gratings.

3. I have reviewed the present patent application, the Final Office Action of July 1, 2008, as well as the main references cited in the Final Office Action, namely U.S. Patent 5,910,962 to Pan

et al. ("REF1"), the article "Dual wavelength modelocked fiber laser" by Town et al. ("REF2"), and the article "Wide-band Fabry-Perot-like filters in optical fiber" by Town et al. ("REF3").

4. I believe that the combination of REF1 with REF2, which refers to REF3, neither discloses nor renders obvious doped fiber having a superstructure grating which forms at least three cavities each occupying a respective portion of the fiber that is unoccupied by any other one of the cavities such that, when an energy signal is applied, different laser wavelengths resonate in respective ones of the cavities.

5. I believe that the set of pairs of Bragg gratings forming REF1's fiber lasers 22A-22D would not be considered a "superstructure grating". The expression "superstructure grating" is well-known and used by those ordinarily skilled in the art to refer to a grating structure fabricated with a modulated exposure over the length of the grating structure. Exhibit "A" to this Declaration contains a copy of page 114 of the book "Fiber Bragg Gratings" by A. Othonos and K. Kalli, Artech House, Boston and London (1999), which supports this. One characteristic of the grating structure constituting a superstructure grating is that there is a well-defined phase relationship between all the parts of the grating structure. The set of pairs of Bragg gratings in REF1 do not constitute a grating structure that is fabricated with a modulated exposure over the length of the grating structure. Rather, the sections of fiber between the Bragg gratings in REF1 have not been subject to any modulated exposure. Also, each pair of Bragg gratings in REF1 does not have (nor does it require) any particular phase relationship with other ones of the grating pairs. Therefore, the set of pairs of Bragg gratings in REF1 would not be considered a "superstructure grating".

6. In REF2, the two overwritten chirped gratings of the comb filter do not form any cavity in which resonates a laser wavelength. Rather, in REF2, there is only one laser cavity and it is formed by the entire optical loop shown in Fig. 1, including the erbium-doped fiber amplifier (EDFA), the chirped grating on each side of the EDFA, and the comb filter (p. 1459, 2nd col., 1st

parag., line 1). The comb filter is a passive filter that is contained within the laser cavity to allow passage of specific wavelengths, but does not itself form any cavity in which resonates a laser wavelength.

7. The two overwritten chirped gratings of the comb filter in REF2 do not form three or more cavities each occupying a respective portion of the fiber that is unoccupied by any other one of these cavities. Specifically, the two overwritten chirped gratings of the comb filter in REF2 are fabricated as discussed in REF3 (p. 1459, col. 2, 2nd parag., line 10). REF3 discusses a Fabry-Perot (FP) resonator made by overlapping two linearly chirped gratings each 4 mm long with a displacement of 0.5 mm between them (p. 79, 1st col.., lines 14 to 17; p. 79, col. 2, line 1 to p. 80, col. 1, line 4; and Fig. 4). Exhibit "B" to this Declaration contains a copy of a paper entitled "Wide-band Fabry-Perot-like filters in optical fibre" by Town et al., published in *Lasers and Electro-Optics Society Annual Meeting*, 1994, LEOS '94 Conference Proceedings, IEEE, and confirming that each of the two linearly chirped gratings of the FP resonator of REF3 is 4 mm long (p. 144, section 4, lines 1 to 3). Exhibit "C" to this Declaration shows a graphical representation of this FP resonator. In this representation, each of the two chirped gratings is represented by a tilted mirror which shows the positions along the optical fiber (horizontal axis) at which different wavelengths are reflected (vertical axis). Since each grating is linearly chirped and has a length of 4 mm and since REF3 specifies that the FP resonator has a spectral range of 175 nm indicating that it reflects wavelengths within this spectral range, the slope of the tilted mirror representing each chirped grating is about 44 nm/mm. REF3 also specifies that the FP resonator has a free spectral range (FSR) of 1.5 nm, meaning that wavelengths transmitted by the FP resonator are spectrally spaced by 1.5 nm. The cavities in which resonate these wavelengths are represented by bidirectional arrows in the graphical representation of Exhibit "C". As can be seen, neighbouring cavities overlap so much that every cavity, except the first and last cavities, does not occupy a portion of the fiber that is unoccupied by any other one of the cavities. Rather, any portion of the fiber occupied by any cavity, except the first and last cavities, is also occupied by a portion of the fiber that is occupied by another cavity. For example, as shown in the zoomed

insert, the cavity X altogether occupies two portions P_1 (in one diagonal hatching) and P_2 (in an opposite diagonal hatching) of the fiber, with the portion P_1 also being occupied by the cavity Y and the portion P_2 also being occupied by the cavity Z.

8. Therefore, I conclude that fabricating the two overwritten chirped gratings of REF2 (as discussed in REF3) on a doped optical fiber would not form at least three cavities each occupying a respective portion of the fiber that is unoccupied by any other one of the cavities such that, when an energy signal is applied, different laser wavelengths resonate in respective ones of the cavities.

9. I believe that it would not have been obvious to fabricate two overwritten chirped gratings as in REF2 or REF3 on a doped optical fiber such that they form at least three cavities each occupying a respective portion of the fiber that is unoccupied by any other one of the cavities such that, when an energy signal is applied, different laser wavelengths resonate in respective ones of the cavities. Firstly, nothing in REF2 or REF3 would lead one to contemplate designing the two overwritten chirped gratings to ensure that they form such three or more cavities, let alone to establish how the chirp of these gratings would have to be selected to do this. Secondly, in both REF2 and REF3, the two overwritten chirped gratings are located on a passive portion of the fiber (i.e., a portion that is not doped to form a gain medium) and there would be no apparent reason to contemplate fabricating such overwritten chirped gratings on an active portion of an optical fiber.

10. For the reasons discussed in paragraph 9, I believe that it would not have been obvious to incorporate the two overwritten chirped gratings of REF2 (fabricated as discussed in REF3) into the laser source of REF1 to form at least three cavities each occupying a respective portion of the fiber that is unoccupied by any other one of the cavities such that, when an energy signal is applied, different laser wavelengths resonate in respective ones of the cavities. In fact, in the unlikely event that one were to replace each pair of Bragg gratings forming a respective one of

REF1's fiber lasers 22A-22D by a respective pair of overwritten chirped gratings from REF2, every pair of overwritten chirped gratings in the resulting laser source would form cavities which (as described in paragraph 7) overlap so much that any portion of the fiber occupied by any cavity, except the first and last cavities, is also occupied by a portion of the fiber that is occupied by another cavity. Thus, every pair of overwritten chirped gratings in the resulting laser source would not form at least three cavities each occupying a respective portion of the fiber that is unoccupied by any other one of the cavities such that, when an energy signal is applied, different laser wavelengths resonate in respective ones of the cavities. This would cause high gain competition and thus discourage multi-wavelength lasing action.

11. Being hereby warned that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001, and that such willful false statements may jeopardize the validity of the application or any resulting patent, I declare that I am properly authorized to execute this declaration; and all statements made of my own knowledge are true and all statements made on information and belief are believed to be true.

Date: 1 April 2009 By: ____________________

This is Exhibit "A" to the Declaration of Dr. Peter Krug

Date: 1 April 2009 By: ____________________

Bragg gratings. The first grating was written at 1550.05 nm and reached a reflectivity of ~100% within 15 seconds (at 30 Hz) of UV exposure and had a linewidth of 0.25 nm. After adjusting the interferometer to write at a different Bragg wavelength, the second grating was written at 1542.6 nm with approximately the same characteristics. Each time a new grating was inscribed, the reflectivity of the existing gratings was reduced. Nevertheless, even after superimposing five gratings, the individual grating reflectivities were higher than 60%. Additionally, the center wavelength of the existing Bragg gratings shifted to longer wavelengths each time a new grating was inscribed because of the change of the effective index of refraction (e.g. the first grating shifted to 1550.975 nm by the time the last grating was inscribed). The shift in wavelength of the first grating after writing all seven gratings corresponds to an effective index of refraction increase of 0.86×10^{-3}.

3.7.2 Superstructure Bragg Gratings

The superstructure Bragg grating refers to a grating fiber structure fabricated with a modulated exposure over the length of the grating [40]. One such approach used by Eggleton et al. [40] was to translate the UV writing beam along a fiber and phase mask assembly while the intensity of the beam was modulated. An excimer-pumped dye laser with a frequency doubler was used to produce 2.0 mJ at 240 nm. Hydrogenated, single-mode, boron-codoped fiber was placed in near contact with a phase mask, and the ultraviolet light was focused through the phase mask into the fiber core by a cylindrical lens, exposing a length of approximately 1 mm. To fabricate a 40-mm long superstructure, the excimer laser was periodically triggered at intervals of 15 seconds to produce bursts of 150 shots at a repetition rate of 10 Hz, while the ultraviolet beam was translated at a constant velocity of 0.19 mm/s along the mask. The resulting period of the grating envelope was approximately 5.65 mm, forming seven periods of the superstructure. The reflection spectrum of this grating structure is shown in Figure 3.16. There is strong reflection at five discrete wavelengths corresponding to the spatial frequencies of the grating, with reflectance varying from 30% to 95%. These superstructure gratings can be used as comb filters for signal processing and for increasing the tunability of the fiber laser-grating reflector.

3.7.3 Phase-Shifted Bragg Gratings

Bragg gratings generally act as narrowband reflection filters centered at the Bragg wavelength because of the stop band associated with a one-dimensional periodic medium. Many applications, such as channel selection in a multichannel communication system, would benefit if the fiber grating could be designed as a narrowband transmission filter. Although techniques based on Michelson and Fabry-Perot interferometers have been developed for this purpose [41], their use requires multiple gratings and may introduce additional losses. A technique commonly used in distributed feedback (DFB) semiconductor lasers [42] can be used to tailor the transmission spectrum to suit specific

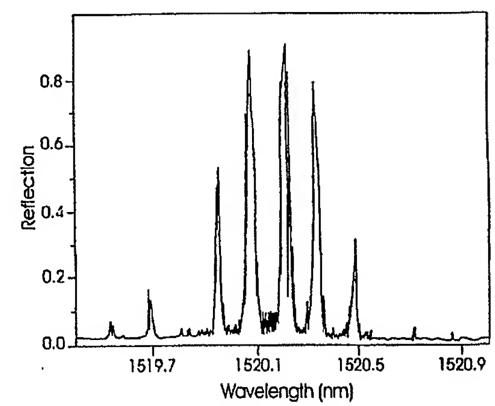


Figure 3.16 Reflection spectrum from a grating superstructure fabricated by translating the UV writing beam along a fiber and phase mask assembly while the intensity of the beam was modulated (*After:* [40]).

requirements. This approach relies on introducing a phase shift across the fiber grating, whose location and magnitude can be adjusted to design a specific transmission spectrum. This is a generalization of an idea first proposed by Haus and Shank [43] in 1976. The principle of the phase shift was demonstrated by Alferness et al. [44] in periodic structures made from semiconductor materials where a phase shift was introduced by etching a larger spacing at the center of the device. This forms the basis of single-mode, phase-shifted semiconductor DFB lasers. A similar device may be constructed in optical fibers using various techniques:

1. Phase masks, in which phase shift regions have been incorporated into the mask design [45];
2. Post-processing of a grating by exposure of the grating region to pulses of UV laser radiation (Figure 3.17) [46];
3. Post-fabrication processing using localized heat treatment [47].

Such processing produces two gratings out of phase with each other, which act as a wavelength selective Fabry-Perot resonator, allowing light at the resonance to penetrate the stop band of the original grating. The resonance wavelength depends on the size of the phase change. One of the most obvious applications includes production of very narrow-band transmission and reflection filters. Moreover, multiple phase shifts can be introduced to produce other devices, such as comb filters, or to obtain single-mode operation of DFB fiber lasers.

For a complete listing of the *Artech House Optoelectronics Library*, turn to the back of this book.

Fiber Bragg Gratings

Fundamentals and Applications in Telecommunications and Sensing

Andreas Othonos
Kyriacos Kalli

Artech House
Boston • London

Library of Congress Cataloging-in-Publication Data
Othonos, Andreas.
Fiber Bragg gratings : fundamentals and applications in telecommunications and sensing / Andreas Othonos, Kyriacos Kalli.
p. cm. — (Artech House optoelectronics library)
Includes bibliographical references and index.
ISBN 0-89006-344-3 (alk. paper)
1. Optical fibers. 2. Diffraction gratings. 3. Optical detectors. I. Kalli, Kyriacos. II. Title. III. Series.
TA1800.084 1999 99-21679
621.36'92—dc21 CIP

British Library Cataloguing in Publication Data
Othonos, Andreas
Fiber Bragg gratings : fundamentals and applications in telecommunications and sensing. — (Artech House optoelectronics library)
1.Optical fiber detectors 2. Telecommunication 3. Optical fibers
I. Title II. Kalli, Kyriacos
621.3'692

ISBN 0-89006-344-3

Cover design by Lynda Fishbourne

685 Canton Street
Norwood, MA 02062

International Standard Book Number: 0-89006-344-3
Cataloging-In-Publication: 99-1679

10 9 8 7 6 5 4 3 2 1

To Demetra, Anna,
&
the children

This is Exhibit "B" to the Declaration of Dr. Peter Krug

Date: 1 April 2009 By: ____________________

Wide-band Fabry-Perot-like filters in optical fibre

Town, G. Sugden, K. Williams, J. Bennion, I. Poole, S.
Dept. of Electr. Eng., Sydney Univ., NSW;

This paper appears in: **Lasers and Electro-Optics Society Annual Meeting, 1994. LEOS '94 Conference Proceedings. IEEE**
Publication Date: 31 Oct-3 Nov 1994
Volume: 2, On page(s): 144-145 vol.2
Meeting Date: 10/31/1994 - 11/03/1994
Location: Boston, MA, USA
ISBN: 0-7803-1470-0
References Cited: 2
INSPEC Accession Number: 5112160
DOI: 10.1109/LEOS.1994.586366
Posted online: 2002-08-06 19:31:18.0

Abstract
An important component in optical systems which has to date been difficult to produce in a format compatible with optical fibre systems is the Fabry-Perot (FP) resonator. Although narrow-band devices have been reported with very high finesse, for applications in short pulse lasers and high speed communication system a response over several nanometres or more is required. The primary problem preventing the fabrication of wide-band filters using unchirped Bragg gratings written in photosensitive optical fibre is that the limited Δn which may be achieved without loss limits the bandwidth of the device. In this paper we demonstrate a method to produce Fabry-Perot-like structures in which the bandwidth is limited primarily by the range of chirp that can be produced in the grating

Index Terms
Inspec
Controlled Indexing
optical fibre filters

Non-controlled Indexing
Fabry-Perot resonator Fabry-Perot-like structures diffraction gratings high speed communication system optical fibre filters optical fibre systems optical systems photosensitive optical fibre short pulse lasers unchirped Bragg gratings very high finesse wide-band Fabry-Perot-like fibre filters

Author Keywords
Not Available

References

No references available on IEEE Xplore.

Citing Documents

No citing documents available on IEEExplore.

Wide-band Fabry-Perot-like Filters in Optical Fibre.

2:15pm - 2:30pm
PD3.3

Graham Town[1], Kate Sugden[2], John Williams[2], Ian Bennion[2], and Simon Poole[3]

(1) Department of Electrical Engineering, University of Sydney, NSW 2006, Australia.
(2) Department of Electronic Engineering and Applied Physics, Aston University, Aston Triangle, Birmingham, B4 7ET, UK.
(3) Optical Fibre Technology Centre, University of Sydney, NSW 2006, Australia.

1. Introduction

An important component in optical systems which has to date been difficult to produce in a format compatible with optical fibre systems is the Fabry-Perot (FP) resonator. Although narrow-band devices have been reported with very high finesse[1], for applications in short pulse lasers and high speed communication systems a response over several nanometres or more is required.

The primary problem preventing the fabrication of wide-band filters using unchirped Bragg gratings written in photosensitive optical fibre is that the limited Δn which may be achieved without loss limits the bandwidth of the device. In this paper we demonstrate a method to produce Fabry-Perot-like structures in which the bandwidth is limited primarily by the range of chirp that can be produced in the grating.

2. Theory

The fundamental structure of the resonator is shown schematically in figure 1. Ideally each grating would be uniform in strength and linearly chirped, and therfore act as a wide-band mirror with reflectivity and bandwidth determined by the strength of the grating, the rate of chirp, and the length of the grating. The free spectral range (FSR) and finesse (F) of the resonator, ignoring losses, are then determined by the reflectivity of each mirror and the spacing between the gratings, as in a standard FP resonator.

The overall response in transmission of the cavity formed by the two chirped gratings is equivalent to that of a FP resonator formed by two partially transmissive plane mirrors, except that the phase response is modified by transmission through the chirped gratings.

3. Method

The gratings were fabricated using a dual beam holographic exposure technique. The fibres were exposed to two interfering beams produced by amplitude division from a CW frequency doubled argon ion laser at a wavelength of 244 nm. The chirp was imposed by using dissimilar wavefronts in the holographic exposure[2] achieved by the introduction of a cylindrical lens into one arm of the interferometer. This provided gratings in hydrogenated boron/germania co-doped fibre with bandwidths in excess of 140 nm from exposures of less than one minute. The hydrogenation process was carried out at room temperature and 150 atmospheres pressure for approximately 5 days.

The gratings were consecutively written into the fibre, and each exposure was monitored on an optical spectrum analyzer. The second grating exposure was halted when the FP fringes reached their maximum modulation depth when measured in reflection.

4. Results

Figure 2a shows the transmission spectrum of a low finesse resonator measured over it's entire spectral range of 175 nm. In this filter each grating was 4mm long, and the displacement between the two gratings was approximately 0.5 mm. The measurement was made using erbium fibre flouresence and an optical spectrum analyser. The data shown is normalized against the spectrum of the source.

Figure 2b shows the transmissivity of the same filter over a range of 10 nm. The resonator had a measured F=1.6, and FSR=1.6 nm, in good agreement with design parameters. Note that to obtain the large FSR in this filter it was necessary to overlap the two gratings in the fibre, however because only low reflectivity was required, each grating could be considered linearly independent.

The transmission spectrum of a different filter with FSR=0.09 nm is shown in figure 3, measured around 1536 nm with a tunable diode laser (HP 8168A, linewidth 0.001 nm) and power meter. In this case the gratings were 4 mm long, and separated by 8 mm. When measured around 1550 nm, the same filter displayed the same fringe spacing and finesse as measured at 1536 nm. Other Fabry-Perot-like resonators have also been fabricated with free spectral ranges from 0.09 to 11.27 nm.

5. Conclusion

Wide-band Fabry-Perot-like resonators may be fabricated in photosensitive optical fibres using distributed mirrors formed by chirped Bragg gratings. The resonators are suitable for use in many applications including pulse multiplication in short pulse fibre lasers, and frequency-guiding filters for soliton systems.

Acknowledgements

This work is supported by the Australian Research Council, and the UK Science and Engineering Research Council. Kate Sugden is supported by Aston University and BNR Europe.

References

1. W. Morey, OFC'92, San Jose, WA2, (1992).
2. M. C. Farries, K. Sugden, D. C. J. Reid, I. Bennion, A. Molony, and M. J.Goodwin. *submitted to Electron. Lett.*

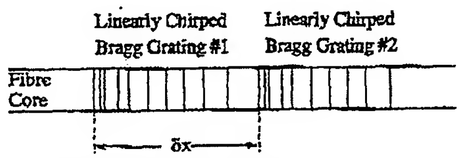


Fig. 1. Schematic of the wide-band Fabry-Perot filter structure.

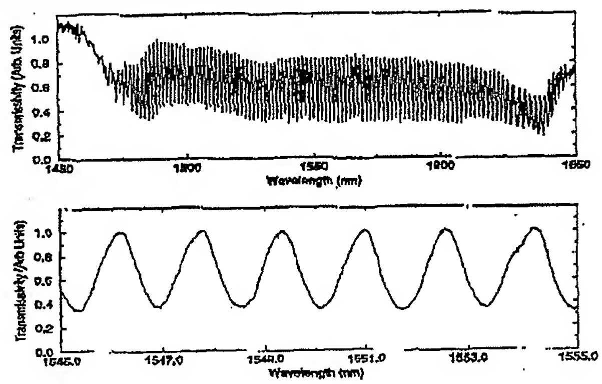


Fig. 2. Transmissivity of a low finesse Fabry-Perot with FSR=1.6 nm measured (a) over it's entire spectral range, and (b) over a 10 nm range.

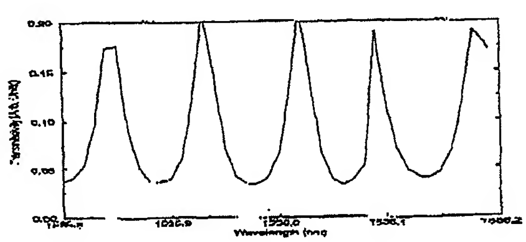
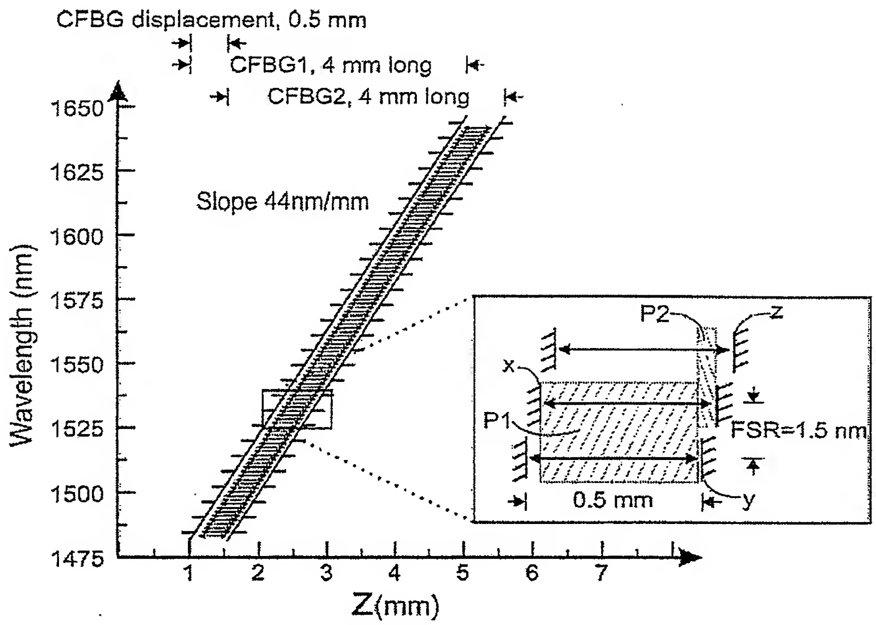


Fig. 3. Measured transmissivity of a Fabry-Perot with FSR=0.09 nm around 1536 nm.

This is Exhibit "C" to the Declaration of Dr. Peter Krug

Date: 1 April 2009 By: ______________________



CFBG displacement, 0.5 mm
CFBG1, 4 mm long
CFBG2, 4 mm long
1650
1625
1600
1575
1550
1525
1500
1475
Wavelength (nm)
Slope 44nm/mm
P2
z
x
P1
FSR=1.5 nm
0.5 mm
y
1
2
3
4
5
6
7
Z(mm)